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Impact of city expansion and increased heat fluxes scenarios on the urban boundary layer of Bilbao using Enviro-HIRLAM

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ABSTRACT

Most of medium-sized coastal cities are in continuous development and therefore the future impacts of urbanization on the atmospheric boundary layer (ABL) over them are expected to become more significant. This study is a complementary study of the urban heat island (UHI) over Bilbao, and its aim is to explore how the properties and structure of the ABL change depending on different urban scenarios during two short periods in summer and in winter under calm wind conditions. The analysis is carried out with the Enviro-HIRLAM model coupled with the Building Effect Parameterization urban module. The scenarios are defined according to two independent drivers: the expansion of the city in several sizes, and the increase of the anthropogenic heat fluxes. This study shows the differences between the scenarios in terms of the horizontal extension of the urban plume and the vertical development of the UHI. The expansion of the city is the driver that has the largest impact on the ABL.

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1. Introduction

Currently, the most common cities are medium-sized, with population ranging between 1 and 5 million people (United Nations, 2011). These cities account for 22% of the world urban population and Europe is exceptional by having 75% of its urban population in medium-sized cities, most of them located near the coast. That share is expected to change, the medium-sized cities will turn into larger ones, and the world urban population is expected to increase up to 60% of the total global in 2030, and up to 82% by 2050 (United Nations, 2011). This evolution implies not only changes in the size and structure of the city, but also changes in the activities that take place within them such as transport, economic-industrial activities, or residential use. In combination with natural local factors (e.g. water systems, vegetation cover, and topography) these changes result in an increase of the land-use changes, emissions of anthropogenic heat, and pollutant substances. Such changes will have different effects on the diurnal cycle of heating and cooling with respect to the rural surfaces and the result of such responses is further modification of the surface energy balance (SEB), an increase of the horizontal gradient in the air temperature and the alteration of the atmospheric boundary layer (ABL) i.e., development of a more intense Urban Heat Island (UHI) (Hidalgo et al., 2008; Masson et al., 2014). For example, during the summer, higher night time temperatures can already lead to nocturnal heat-stress and disrupted sleep for city residents in some parts of the world, exposing them to higher health-related risks during heat waves. During the day, urban surfaces exposed to the sun can become very hot, resulting in even greater discomfort. During the heat wave experienced in Europe in 2003, most casualties took place in major towns and cities (Beniston, 2004). Those alterations can have significant consequences on factors such as the standard of living, economic development etc. and it is relevant to address this issue through different adaptation strategies to improve the situation. A review of the state-of-the-art and the interaction between climate change, city structures and economies can be found in Masson et al. (2014).

This study analyses the metropolitan area of Bilbao, a one million people coastal city located in the Basque Country Region, north of Spain. In the last decade the urban climate of Bilbao has been exhaustively studied conditions (Millán et al., 1987; Acero, 2012; González-Aparicio et al., 2012): the urban impact on the ABL has only appeared under calm and stable. In addition, Acero et al. (2013a) have recently studied the UHI intensity showing that seasonal variation of the UHI is directly related with regional sea breeze. They stated that the influence of sea breeze causes a positive relative humidity anomaly during the afternoon as well as an urban cold island especially in summer time when sea breeze intensity is higher. This assessment was the initial step to assess the urban climate from an urban planning perspective and develop an Urban Climate Map (Acero et al., 2013b). In addition, González-Aparicio et al. (2012) studied the urban boundary layer (UBL) using meteorological modelling coupled with urban parameterisation. The mesoscale online coupled meteorology-chemistry transport model Enviro-HIRLAM (Baklanov et al., 2008; Korsholm et al., 2009) with the implemented Building Effect Parameterization (BEP) urban module (Martilli et al., 2002; Mahura et al., 2008) was used in order to: (1) evaluate the ability of the model to simulate the land–sea breezes over a complex terrain, (2) evaluate the simulations with the integration of the urban parameterisation in Enviro-HIRLAM over a medium-sized city, and (3) analyse the urban impacts on the ABL over Bilbao. In particular, the study determines the horizontal extension of the urban plume, the current impact of the sea breeze regimes on the horizontal and vertical development of the UHI, and the impacts on the concentration levels of pollutants. The UHI is around 1 °C with an extension of about 130 km^2 and the hot air mass is transported up to 12 km by the land breezes. The intensity was found to be lower in a winter than in a summer case, indicating that the predominant factor for the development of the UHI is the surface heating during the day time.

Moreover, there is an extensive literature about the evolution of the regional climate of the Basque Country (Chust et al. (2011), Climate Change in the Basque Country (2012), González-Aparicio and Hidalgo (2011)). In terms of extreme temperatures, González-Aparicio and Hidalgo (2011) showed that maximum temperatures are expected to increase up to 3.5 °C and 3 °C for summer and winter seasons, respectively during the 21st century (2000–2100). For summer seasons, heat waves will increase by 30% in duration and for winter seasons the cold waves will tend to disappear.